U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

# New Reactors: Striving for Enhanced Safety

*An NRC new reactor vendor inspector observes ultrasonic testing inside a steam generator.*


*An NRC inspector reviews a shipment of materials at the Vogtle site in Georgia.*

*NRC inspectors visit Japan Steel Works to review quality controls for important plant components.*

*Front cover, left: NRC geologists and inspectors examine the excavation of the V.C. Summer Unit 2 foundation in South Carolina.*

*Front cover, right: Work in progress on the "nuclear island" at the Vogtle Unit 3 site in Georgia. (Courtesy: Southern Company, Inc.)*

## Contents



## Introduction

The U.S. Nuclear Regulatory Commission (NRC) was created by Congress in 1974 as an independent agency. The NRC regulates the Nation's civilian use of nuclear materials, including nuclear power plants, to ensure adequate protection of public health and safety, to promote the common defense and security, and to protect the environment.

***Hope Creek Nuclear Power Plant in New Jersey***

All 104 operating nuclear power plants in the United States were subject to a rigorous licensing process, described in Title 10 of the *Code of Federal Regulations* (10 CFR), Part 50, "Domestic Licensing of Production and Utilization Facilities." The NRC approved construction of these plants between 1964 and 1978 and granted the most recent operating license in 1996. These plants continue to operate safely today and are constantly monitored through inspections and licensing reviews.

Following the licensing of these reactors, the NRC implemented a strategy for licensing the next generation of nuclear power plants, linking the foundation of safety provided by the NRC's regulations with the industry's desire for continuous improvement. This brochure describes key NRC policies, rules, and guidance that contribute to enhanced safety for new reactors being proposed today.

## Safety goals for nuclear power plants

In 1986, the Commission published its policy statement on safety goals for the operation of all nuclear power plants. This statement, developed with extensive public input following the 1979 accident at Three Mile Island (TMI), established goals to define an acceptable level of radiological risk for nuclear power plants.

The policy statement provides two high-level, qualitative goals:

> *Individual members of the public should be provided a level of protection from the consequences of nuclear power plant operation such that individuals bear no significant additional risk to life and health.*
>
> *Societal risks to life and health from nuclear power plant operation should be comparable to or less than the risks of generating electricity by viable competing technologies and should not be a significant addition to other societal risks.*

In addition, the statement translates these goals into quantitative objectives related to the risk of accidental or cancer-related death.

As noted in the discussion supporting the policy statement, these goals represent a low level of risk to public health and safety that the industry should strive to meet.

## Fundamental policies for new reactors

In the 1980s, the NRC also began to develop its strategy for licensing the next generation of reactors. This strategy benefited from years of experience with the operating reactors, insights gained from detailed assessments of those plants, and research results.

Through a series of policy statements and interactions with staff, the Commission developed fundamental policies for new reactors that considered this wide experience base and improved technology.

### *Protection from severe accidents*

Nuclear power plant applicants must demonstrate that their facility can withstand a broad range of abnormal conditions and accidents—"design-basis accidents"—without releasing harmful amounts of radioactive material. More serious accidents, termed "severe accidents," are expected to occur much less frequently, but they could have more significant consequences. In the 1985 policy statement on severe accidents, the Commission presented its policy for reducing the likelihood and mitigating the consequences of these types of accidents.

Owners of operating nuclear power plants had made numerous improvements to the design and operation of their plants to address severe accident issues. Many of these updates were identified during followup to the TMI accident or through ongoing evaluation of plant operations. At the time the policy statement was issued, therefore, the Commission felt confident it did not need to require further generic actions for operating power plants.

***Control room response to the TMI accident***

For new plants, the Commission had more to say in the policy statement:

> *...this should not be viewed as implying a Commission policy that safety improvements in new plant designs should not be actively sought. The Commission fully expects that vendors engaged in designing new standard (or custom) plants will achieve a higher standard of severe accident safety performance than their prior designs.*

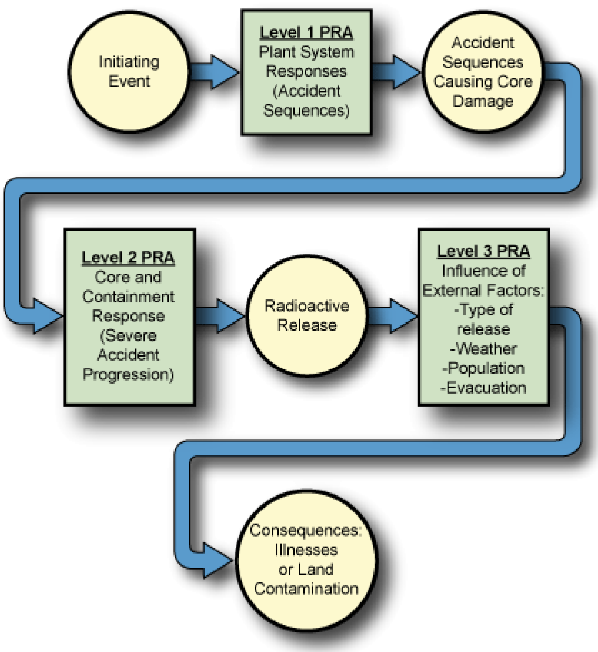
Specifically, the Commission encouraged vendors to design plants that were simpler and gave operators more time to react to failures or unexpected conditions.

In addition, the severe accident policy statement established specific criteria for new designs. Applicants submitting new designs for NRC approval could address severe accidents acceptably if they did the following:

- complied with the current regulations, including those added in response to the TMI accident

- resolved specific safety issues, with a special focus on reliability of decay heat removal and electrical power

- completed a probabilistic risk assessment (PRA)[1] and considered severe accident vulnerabilities




*The phases or "levels" of a PRA*

In completing these steps, applicants would consider a range of alternatives in addressing safety issues and reducing risk from severe accidents. The staff would reach a conclusion on the acceptability of the design through a review of the applicant's traditional engineering analysis, complemented by insights from the PRA.

## Advanced reactor designs

In 1986, the Commission issued its policy statement on the regulation of advanced nuclear power plants. In keeping with the "advanced" designation, the Commission stated its expectation that these reactors "would provide more margin prior to exceeding safety limits and/or utilize simplified, inherent, passive, or other innovative means to reliably accomplish their safety functions."

The policy statement went on to list attributes that should be considered in advanced designs, such as the following:

- simplified safety systems that would need fewer operator actions

- reliable equipment that would reduce the need to activate safety systems

- easily maintainable equipment that would expose plant personnel to less radiation

*Nuclear power plant workers wearing protective clothing to reduce radioactive contamination*

[1] PRAs estimate risk using calculations related to what can go wrong, how likely that occurrence is, and what the consequences would be. In the nuclear industry, PRAs are often used to understand strengths and weaknesses of the design and operation of a nuclear power plant.

### Which kind of reactor?

The different terms for types of reactors can be confusing. **New** reactors are often considered to be any reactors envisioned in addition to the fleet of 104 currently operating reactors.

The current fleet consists mainly of large reactors that use regular water ("light" water, as opposed to "heavy" water that has a different type of hydrogen than commonly found in nature) for both cooling the core and facilitating the nuclear reaction. These reactors are called **large light-water reactors**.

Reactors can be categorized by the types of systems they use. **Evolutionary** designs, as with earlier large light-water reactor designs, have "active" safety systems powered by alternating current (ac). **Passive** designs rely on physical phenomena such as gravity and natural cooling, as well as longer lasting batteries rather than ac-powered systems, for a specified time (e.g., 72 hours) following an accident.

When these policies were being developed in the 1980s, **advanced** was the term used for reactors significantly different from those that were being constructed or operated. At the time, such designs included high-temperature gas-cooled reactors, liquid-metal-cooled reactors, and light-water reactors of innovative design. Passive designs such as the Westinghouse AP600 (and later AP1000) were suitably innovative to be categorized as "advanced."

Today, the passive large light-water reactor designs are generally grouped with other evolutionary large light-water reactors and termed simply **new reactors**. These designs include the AP1000, the General Electric Hitachi Economic and Simplified Boiling-Water Reactor (ESBWR—also a passive design) and Advanced Boiling-Water Reactor (ABWR), the AREVA U.S. Evolutionary Power Reactor (U.S. EPR), and the Mitsubishi U.S. Advanced Pressurized-Water Reactor (US-APWR).

In the NRC's Office of New Reactors, the Advanced Reactor Program manages licensing activities for three categories of **advanced reactors**: small modular light-water reactors, high-temperature gas-cooled reactors, and liquid-metal-cooled reactors.

Regardless of design or terminology, all of these designs receive a full safety review by the NRC before being licensed for operation in this country.

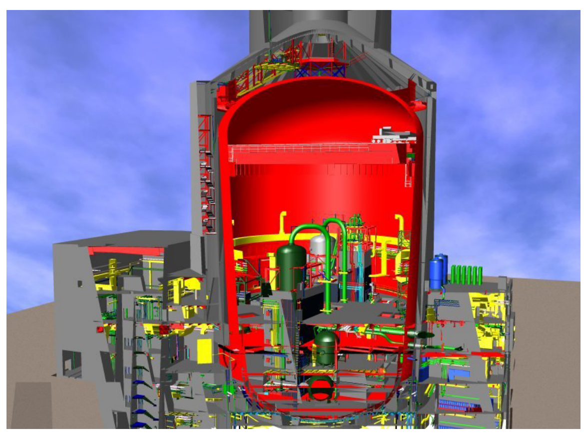
# New reactor specifics

In addition to these general policies, the Commission realized the value of enhancements in certain technical areas. Through a series of policy papers, the Commission directed the staff to impose certain new features and programs on proposed designs.

## *Enhancements for new reactors*

In January 1989, the NRC staff informed the Commission of the planned approach to ongoing reviews of evolutionary new reactor designs. The staff identified several issues that should be resolved for these designs, such as fire protection, station blackout, and maintenance of design reliability.

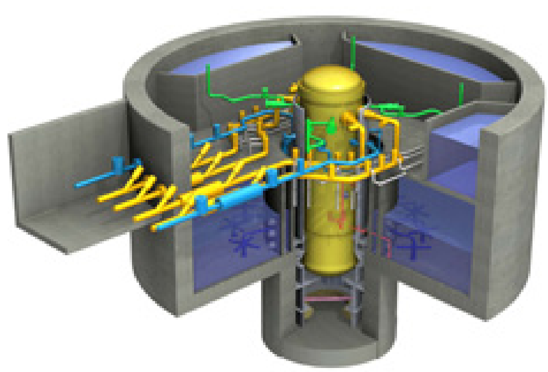
A year later, the NRC staff presented the Commission with recommendations on a number of issues fundamental to agency decisions on evolutionary designs. The Commission approved most of these recommendations, sanctioning a number of key enhancements for new reactors.



*The AP1000 reactor design (Courtesy: Westinghouse)*

These enhancements include the following:

- a diverse system to ensure shutdown of the reactor even if the main system fails
- design features to ensure high reliability of the shutdown decay heat removal system
- an alternate ac power source to mitigate station blackout
- additional requirements for fire protection, including ensuring safe shutdown without operator intervention, even if a fire disables all equipment in one fire area
- methods for core debris spreading and cooling if a severe accident were to occur
- a depressurization system and reactor cavity design features to contain ejected core debris if a severe accident were to occur



*The ESBWR reactor design*

A few years later, as the NRC began to review passive designs, the staff requested Commission direction on extending certain requirements to passive designs, as well as direction on additional enhancements.

In response, the Commission extended a number of its previous positions, such as those on enhanced fire protection, core debris coolability, and high pressure core melt ejection, to passive designs. The Commission also approved new positions on topics such as common-cause failures of instrumentation and control systems and steam generator tube ruptures.

In response to these Commission policies, new reactor applicants included a number of additional features in the designs they submitted to the NRC.

## Design-specific enhancements

The Commission has also made policy decisions on design-specific enhancements to ensure protection of the public and the environment.

For example, the Westinghouse AP600 design originally relied only on natural processes to remove radioactive material from the air in containment during a severe accident. Though these natural removal processes remove sufficient radioactive material during design-basis accidents, the staff determined that an active system would give the staff greater confidence in the design's response to severe accidents.

As a result, the Commission approved the staff's recommendation that the AP600 be required to add a containment spray system. This system was included in the certified design specifically to address severe accidents and was not credited to mitigate any design-basis accident.

## Non-light-water reactors

In 2003, the Commission clarified its expectations for enhanced safety relative to reactor designs that cool the core using an inert gas or liquid metal instead of water. Similar to the policy for light-water reactors, reactor designers are expected to propose designs with enhanced safety characteristics; as needed, the NRC staff will recommend additional enhancements in areas of high uncertainty, subject to Commission endorsement. These enhancements could include additional design features or testing, as well as additional review or oversight by the NRC.

## Implementing the policies

The NRC has implemented the Commission's policies on new reactor safety through rules, guidance, staff reviews, and inspection.

### 10 CFR Part 52

The Commission approved issuance of 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," in 1989, with a major update in 2007. The regulations in 10 CFR Part 52 provide for standardized reviews of designs, sites, and license applications for new nuclear power plants. These requirements formalize the criteria for new designs identified in the policy statement on severe accidents.

In 10 CFR Part 52, the NRC also included further requirements related to severe accidents. Design certification applicants must provide a description and analysis of design features that prevent or mitigate specific severe accident phenomena (e.g., steam explosion, containment bypass). They must also provide an environmental report that addresses the costs and benefits of adding more severe accident mitigation features.

In addition, the rule includes the expectation that new reactors will reflect an extremely low probability of accidents that could result in the release of significant quantities of radioactive material.

### Certified designs

When the NRC certifies a new reactor design, it documents the certified portion of the design in an appendix to 10 CFR Part 52. This process means that the important features of these designs are recorded as rules that must be followed by applicants who wish to build that design.

*The ABWR reactor design*

Vendors' consideration of the policies described above resulted in certified designs that reflect an enhanced level of safety compared with currently operating reactors. Because the Commission's intention was to maintain this level of safety throughout plant operation, the design certification rules include a statement that the Commission will deny exemptions from the certified design that would "result in a significant decrease in the level of safety otherwise provided by the design." In the documentation that accompanied the first design certifications, the Commission emphasized its expectation that the industry would cooperate with the NRC to maintain this level of enhanced safety.

The design certification rules also include a special change process to ensure that the features developed to protect against severe accidents would be maintained. The NRC staff must review proposed changes that affect design features that deal with "ex-vessel" accidents, where core material leaves the reactor vessel, if there would be a substantial increase in the probability or consequences of these types of accidents.

## Aircraft impact rule

Another rule that implements the Commission's expectation of enhanced safety is 10 CFR 50.150, "Aircraft Impact Assessment," issued in 2009. This rule requires new reactor applicants to assess what would happen if a large commercial aircraft hit their plant and to show that harmful amounts of radioactive materials from the reactor core and spent fuel would not be released to the environment.

The supplementary information that accompanied the final rule explicitly states that the rule "provides an enhanced level of protection beyond that which is provided by the existing adequate protection requirements." The discussion refers to the policy statements on severe accidents and advanced reactors, emphasizing that–

> *This regulatory approach has demonstrated its success, as all designs subsequently submitted to and certified by the Commission represent substantial improvement in safety for operational events and accidents. The final aircraft impact rule will further enhance the safety of new nuclear power plants for aircraft impacts and is consistent with these policy statements.*

## Risk insights

As discussed in the policy statement on severe accidents and codified in 10 CFR Part 52, new reactor applicants must develop a PRA and use insights from the PRA to reduce the risk from severe accidents. In response, applicants have reduced the risk of their reactors through a number of design changes.

For example, the ABWR includes a number of design and procedure modifications that the applicant chose to make based on risk insights. These changes included the following:

- an ac-independent means of spraying water in containment
- a containment overpressure protection system
- a type of concrete that would limit production of noncondensible gases during a severe accident

***The U.S. EPR containment building (Courtesy: AREVA NP)***

More recently, the AP1000 design incorporated multiple enhancements based on PRA insights, including the following:

- changing the type or normal position of certain valves to improve reliability
- modifying the core design to reduce the risk from potential failures to shut down the reactor

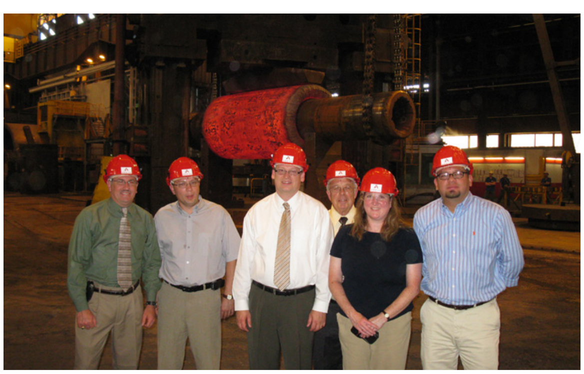
- selecting an optimal design for an accumulator tank that would quickly replenish water during an accident

Applicants' risk assessments and related design changes, therefore, have contributed to the enhanced safety of new reactors.

### *Staff reviews and inspections*

Before the NRC certifies a design or licenses a plant to operate, the NRC staff completes a thorough technical review to ensure that the plant will be safe and secure and meet all relevant requirements. In this review, the staff uses guidance documents that provide additional detail on how to implement the NRC's requirements.

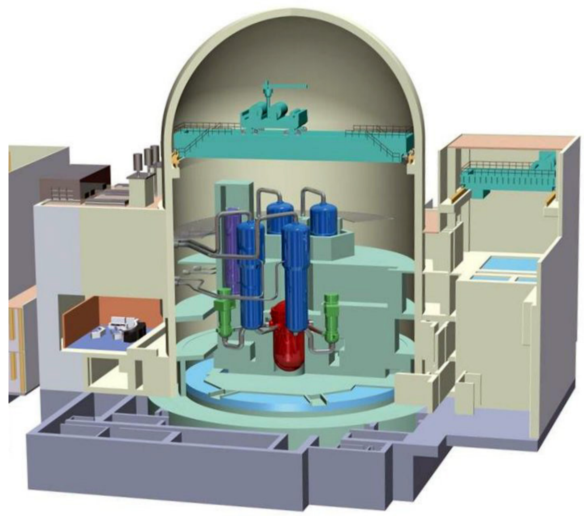
Many of these guidance documents refer directly to policies and regulations described in this brochure. There is guidance for applicants on how to implement enhancements in fire protection and PRA, to name just two. There is also guidance for NRC staff on how to perform the safety review. For example, the guidance for reviewing PRA information acknowledges that designs may incorporate features intended to make the plant safer and easier to operate. Accordingly, the staff determines whether the design represents a reduction in risk compared to existing plants.



*NRC inspection team in front of an 11,300-ton press at Creusot Forge in France*

The NRC is also implementing a stringent construction inspection program to ensure that the facility is constructed in the way it was licensed. Resident inspectors will oversee daily activities at each new reactor construction site. Additional regional inspectors and technical staff will participate when needed. Using a risk-informed approach, the NRC determines how serious an inspection issue is and follows up with more inspections or other penalties when warranted.

These activities ensure that the Commission's requirements and expectations related to new reactor safety and security are met.



*The US-APWR reactor design (Courtesy: Mitsubishi)*

## Conclusion

The NRC is confident that the current generation of nuclear power plants is operating safely. This conclusion is supported by rigorous licensing reviews, improvements that have resulted in reduced radiological risk, and daily inspections.

New reactor designers have used technology improvements, operational experience, and insights from PRAs to make their designs even safer. The Commission has consistently encouraged these objectives and, when needed, imposed additional requirements to enhance safety.

As a result, new reactor designs benefit from significant enhancements in safety. The NRC's reviews of these designs continue to support its mission of protecting public health and safety and the environment.

## References


1. *U.S. Code of Federal Regulations*, "Domestic Licensing of Production and Utilization Facilities," Part 50, Chapter I, Title 10, "Energy."
2. "Safety Goals for the Operations of Nuclear Power Plants; Policy Statement; Republication," Volume 51 of the Federal Register (FR), page 30,028, August 21, 1986.
3. "Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants," 50 FR 32138, August 8, 1985.
4. "Regulation of Advanced Nuclear Power Plants; Statement of Policy," 51 FR 24643, July 8, 1986, revised in 59 FR 35461, July 12, 1994.
5. SECY-89-013, "Design Requirements Related to the Evolutionary Advanced Light Water Reactors," January 19, 1989.
6. SECY-89-102, "Implementation of Safety Goal Policy," March 30, 1989, and associated Staff Requirements Memorandum (SRM), June 15, 1990.
7. SECY-90-016, "Evolutionary Light Water Reactor (LWR) Certification Issues and Their Relationship to Current Regulatory Requirements," January 12, 1990, and associated SRM, June 26, 1990.
8. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," April 2, 1993, and associated SRM, July 21, 1993.
9. NUREG-1503, "Final Safety Evaluation Report Related to the Certification of the Advanced Boiling Water Reactor Design," July 1994.
10. SECY-97-044, "Policy and Key Technical Issues Pertaining to the Westinghouse AP600 Standardized Passive Reactor Design," February 18, 1997, and associated SRM, June 30, 1997.
11. SECY-03-0047, "Policy Issues Related to Licensing Non-Light-Water Reactor Designs," March 28, 2003, and associated SRM, June 26, 2003.
12. "Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Reactors [10 CFR Part 52]," 54 FR 15372, April 18, 1989.
13. "Licenses, Certifications, and Approvals for Nuclear Power Plants [Revised 10 CFR Part 52]," 72 FR 49352, August 28, 2007.
14. NUREG-1793, "Final Safety Evaluation Report Related to Certification of the AP1000 Standard Design," September 2004.
15. Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," June 2007.
16. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Section 19.0, "Probabilistic Risk Assessment and Severe Accident Evaluation for New Reactors," June 2007.
17. "Policy Statement on the Regulation of Advanced Reactors," 73 FR 60612, October 14, 2008.
18. NUREG-0800, Section 9.5.11, "Fire Protection Program," March 2009.
19. "Consideration of Aircraft Impacts for New Nuclear Power Reactors," 74 FR 28112, June 12, 2009.
20. Regulatory Guide 1.189, "Fire Protection for Nuclear Power Plants," October 2009.
21. SECY-10-0121, "Modifying the Risk-Informed Guidance for New Reactors," September 14, 2010, and associated SRM, March 2, 2011.
22. DC/COL-ISG-018, "Interim Staff Guidance on Standard Review Plan, Section 17.4, Reliability Assurance Program," March 2011.
23. NUREG/BR-0314, Revision 2, "Protecting Our Nation: A Report of the U.S. Nuclear Regulatory Commission," June 2011.

NUREG/BR-0356
November 2011